# dB? OR NOT dB?

BY MICHAEL JAMES

With apologies to William Shakespeare, that's the question; but what is the answer? Actually, there are several answers and I'd like to thank Roger Stagnol of Ballantine Laboratories and Harold Engelke, W2IBM, for their valuable help in finding them.

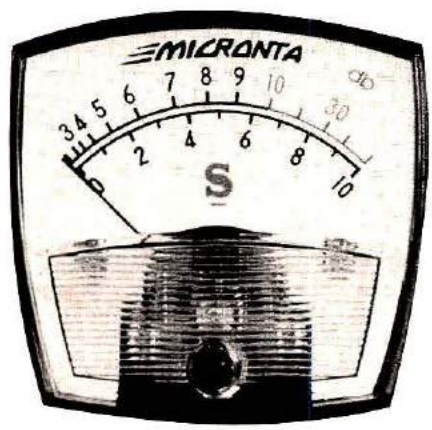
DB stands for decibel, one-tenth of a bel. Okay, so what's a bel? Well . . . the bel was named for Alexander Graham Bell, inventor of the telephone. It seems that the American Telephone and Telegraph Company had been using "a mile of standard cable" as their signal level reference device. The ratio between the volume of the signal put into one end of the cable, and that of the same signal taken out at the other end of the cable was called a "transmission unit." In other words, the cable served as an attenuator and provided a not-so-handy comparison device for determining signal strength ratios.

In 1924 an international advisory committee, including representatives of the Bell Telephone System, met to establish international standards for the transmission and reception of voice signals by "land line," that is, telephone wires. It was agreed that the representatives should recommend to their respective countries that AT&T's standard "transmission unit" be adopted, since it conveniently represented a logarithmic power ratio between input and output signal strengths. One of the delegates to the conference (perhaps a Bell System representative?) suggested honoring the inventor of the telephone sounder — Bell — by changing the name of the standard unit to "bel," when it was calculated with logarithms to the base ten, and "neper" when calculated with natural logarithms to the base *e*. It seems that neper is a contraction of Napier, the Scottish sheep farmer and mathematician credited with discovering the principle of natural logarithms. In any case, two famous persons were honored that day, and the names have stayed to the present.

One thing more: The bel was an inconveniently large value for use in those days of small amplification factors and limited power ratios, so the conferees decided to adopt a smaller and more commonly workable unit. Coincidentally (?) one standard "transmission unit" was exactly equal to one-tenth of a bel, so it was approved then and there to adopt the *deci*bel as the working unit of measurement.

Perhaps it isn't so coincidental after all, humans being what they are, for even today the same things are being called by different names while very different things are often called by the same name.

For those malcontents among us who are unwilling to let matters rest where they are, and who insist upon a more technical explanation, I must beg the pardon of the rest of you for that which is to follow. Stick around if you like, otherwise split; you're excused.




The S-meter of a typical amateur radio communications receiver has a scale that indicates signal strength in S-units up to S-9, and in decibels (dB) over S-9.

The $bel = log\ P1/P2$, and the $decibel = 10\ log\ P1/P2$, where $P1$ is the power level being considered and $P2$ is the standard or "reference" power level. Okay so far? Fine, let's use an example. Suppose your transmitter uses an input power of 100 watts, but you're planning for a kilowatt amplifier and want to know how many dB that will boost your signal. From the formula: ($n$ is number of dB)

$$n = 10\ log\ \frac{1000}{100}$$

$$= 10\ log\ 10$$

and since "log 10" is equal to 1, then the power ratio, $n = 10\ dB = 1\ bel$. Simple, huh?

There's another ratio used in radio work, and that is a ratio between two *voltages*. Want to find out how that is figured in dB? Thought so! By a variation of Ohm's Law, power $P$ is equal to the square of the voltage divided by resistance (or impedance, in ac circuits). If you want to compare two voltages at the same impedance it is simple to let the impedance equal an arbitrary 1; and the ratio is $(V1/V2)^2$. In logarithmic form, the ratio in decibels is therefore $n = 20\ log\ V1/V2$. In an example, suppose you wanted to know the voltage ratio between 2000 volts on the plates of your linear amplifier, and 200 volts on the plate of a driver tube in your exciter. Here we go . . .

$$n = 20\ log\ \frac{2000}{200}$$

$$= 20\ log\ 10$$

but you already know

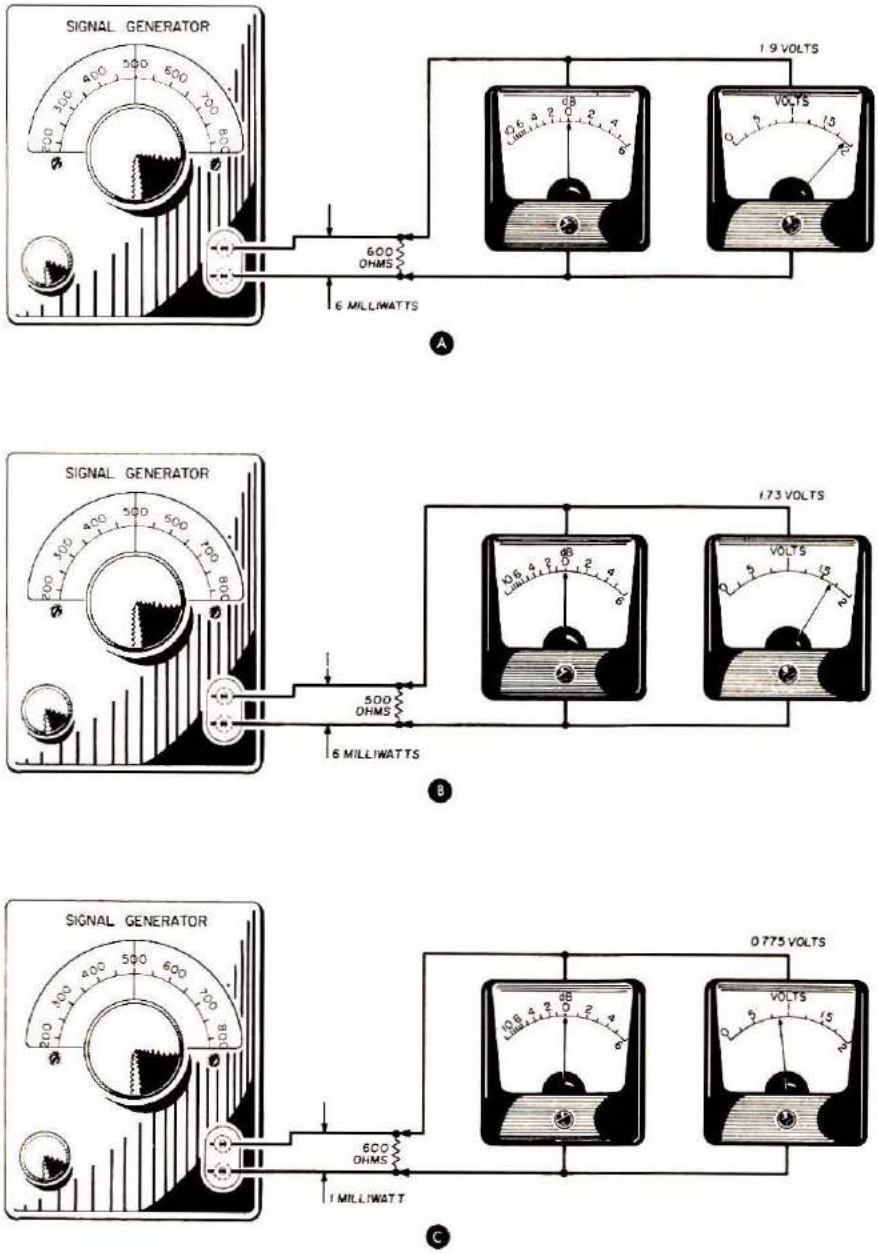



**Fig. 1.** Shows how different reference levels relate to power, voltage and dB. Present standard **A** uses 6 milliwatts across a 600-ohm load to read zero dB. Old standard **B** used 6 milliwatts across 500 ohms. Earliest standard **C** used 1 milliwatt across 600 ohms. Note that in all cases the dB meter reads the same, but that the voltmeter reads 1.9 volts, 1.73 volts and 0.775 volt, respectively.

(remember?) that log 10 is 1, so

*n = 20 times 1*
*= 20 dB or 2 bels*

That wasn't too bad was it?

To figure power or voltage ratios when the values are less than one volt or one watt, what do you do? Again, it's simple: the logs have negative values and the decibels are expressed in negative numbers. For example – 10 dB is one-tenth the power and – 20 dB is one-tenth the voltage.

Welcome back to those who left for awhile. Would you like to know what other, practical uses are made of these numbers? Well, for example, antenna *gain* is a power ratio between a reference antenna and an antenna that you're testing. Hopefully, the decibels will be positive integers in this case.

Or beam width — how "sharp" or "narrow" is the lobe radiated by your Yagi array or your cubical quad? A pattern plot is taken with a field strength meter every ten degrees or so around the antenna, and the results are drawn on a piece of paper. A line is drawn from the center of the paper through the "half-power" points of the pattern, that is, where the power is 3 dB less than it was directly in front of the array. The angle between these two lines is the beamwidth of your antenna. That's right, Bunky, half the power is – 3 dB and twice the power is + 3 dB.

Then there's the good ol' hearing aid — your receiver. Do those funny numbers on the S-meter confuse? If so, just bear in mind that we're talking about *reference* values again. When your receiver was calibrated at the factory, a signal of known strength was applied at the antenna terminals, and the S-meter was adjusted to read S-9. You will notice that the numbers to the left of S-9 on the meter are single integers. These are "S-units," and the meter scale is calibrated such that each S-unit represents about twice the voltage of the next lower value; that is, about 6 dB. To the right of the meter center, the values are given in double integers, such as 10, 20, 30, 40 . . . dB over S-9.

Be assured that meters are not linear, and at low signal strengths the meter jumps around quite lively with only modest changes in signal strength. Above S-9, the meter responds only sluggishly — at best — to very large changes of signal strength. This is done purposely for a couple of reasons: First, to give the meter a logarithmic scale (or close to it), and second, to prevent extraordinarily strong signals from breaking the meter movement or pointer. Besides, if a station is over S-9 on your meter, he's gosh-awful loud. It doesn't make much difference whether the signal is 30 or 40 dB over S-9, unless someone is on an ego trip!

A signal that registers S-9 + 40 dB is about 10,000 times stronger than a signal that shows S-9 on the meter.

**Audio measurements**

Decibels are also used in the measurement and evaluation of sound intensity and its electrical equivalent. The volume produced by a "rock" group, that of an air hammer, or the sound of the Anglo-French Concorde taking off from Dulles International can be measured and recorded in decibels. A far cry from ham radio, you say? Well — maybe not! Stay tuned-in for a few minutes and then decide.

Sooner or later, as a radio amateur, you're going to be dealing with sound and its measurement. It may be the sound coming out of the loudspeaker of your receiver, it may be the sound put into your transmitter by your microphone, or it could even be the sound put into your telephone line when you decide you need a "phone patch."

Let's kick that last item around a bit. Ma Bell is pretty strict about how much voltage you can put into the equipment she owns, and there's a good reason, too. Excessive sound power applied to the telephone lines produces interference — *crosstalk* — and the phone company talks cross to you if you crosstalk them!

Then there's the possibility that you may want to do a bit of voice or music recording, but you don't want the tape you make to sound distorted; after all, it's hi-fi, right? Okay, you're going to have to control audio *level*, the amount of sound you put on the tape. When sound is still audible, its quantity or intensity is referred to as volume or loudness, but when it is converted to electrical signals its quantity if referred to as amplitude or level. Therefore, audio level is the electrical analog of sound intensity, and it must be controlled for your radio equipment to function properly. Television and radio broadcast stations devote a great deal of time and money to the measurement and control of audio level.

When a radio signal is made to carry sound, it is said to be modulated. Speech and music — as well as other audible sounds — can modulate a radio signal. Some sounds have a constant frequency (pitch) and a constant amplitude (loudness). An example of such a sound would be the tone produced during one of the emergency radio alert broadcasts.

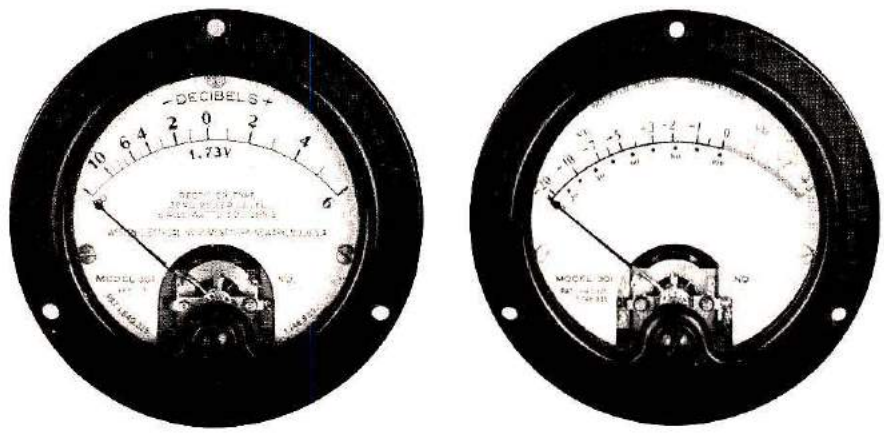
Other sounds have constantly changing pitch and amplitude. Music and speech are examples of constantly changing sounds. We know that radio and TV stations must be able to accommodate both kinds of sounds and reproduce them faithfully, so the place they must begin is the same place you and I must begin — the measurement of sound. Normally, it is necessary to measure only the loudness or level of the audio material, so let's start with that.

**The measurement of sound**

When sound is converted to electrical pulses or signals, these signals have all ohe characteristics of electricity: Current, voltage and power — things that can be measured by instruments called meters. Did you know that the word meter means measure? Fine, glad you did, because we're going to talk about meters and metering.

In working with sound and its electrical equivalent, engineers use two basic kinds of meters. One kind is called a decibel (dB) meter and the other kind is called a volume unit (VU) meter.[1,2] Both measure ac voltage, but in a slightly different way because of the way the meters are constructed. The dB meter measures audio level in decibels compared to a reference level, while the VU meter measures audio level in volume units compared to a reference level. The main difference between the dB meter and the VU meter is that the VU meter is built to follow the complex waveforms of speech and music that bounce up and down in level (intensity) and frequency (pitch or tone); whereas the poor dB meter can't follow the changes at all, but only reads some fixed value of intensity.

Now you may wonder why anyone would ever want to have a dB meter at all, and the answer is simple: It's great for accurately measuring audio signal levels of substantially constant frequency and amplitude and for comparing input and output levels of an




A typical broadcast-type dB meter is shown next to a typical VU meter. Both are commonly used by radio and TV stations for the purpose of measuring signal levels, and controlling them to predetermined values.

audio amplifier. A pure sine-wave output from an audio signal generator is an example of such a signal; the tone put out by WWV is another; and the radio emergency alert signal is still another. Of course, these do change slightly in amplitude — but so gradually that the dB meter can easily follow.

By now, you've probably figured that the VU meter can serve as a dB meter, but the dB meter cannot be used as a VU meter, and that's true. That's why most broadcast stations monitor program level with VU meters — they're versatile and can follow the constantly changing tones and amplitudes of music and speech.

Some meters have a little switch on them whereby they can be changed from reading dB to reading VU, and vice versa, but they are very expensive.

I mentioned reference levels, because if you want to know where you are, or where you're going, you must know where you've been — just like on a map. Your starting point is a reference, and so it is with audio-level measurement.

Although many different references have been used as standards over the years, the one commonly accepted as the *zero dB standard* is the meter deflection produced by a power of one milliwatt (0.001 watt) applied across a 600-ohm impedance. If someone wants to set some point other than zero on a meter scale as a reference point, that is their business, but the industry uses the zero-dB point as standard. This point on the scale is usually *not* at the left-hand edge, however, for reasons we'll mention later.

Other standards have been used, and among the most common are 6 milliwatts across 600 ohms, followed — as a close runner-up — by 6 milliwatts across 500 ohms. It is easy to see that a meter calibrated to one standard will not accurately represent a level adjusted to another standard. It is therefore necessary to know by which standard your meter has been calibrated. It is also necessary to know the impedance of the circuit which your meter is measuring the level of a signal, just in case the meter you have was calibrated for the zero dB reference point with another impedance.

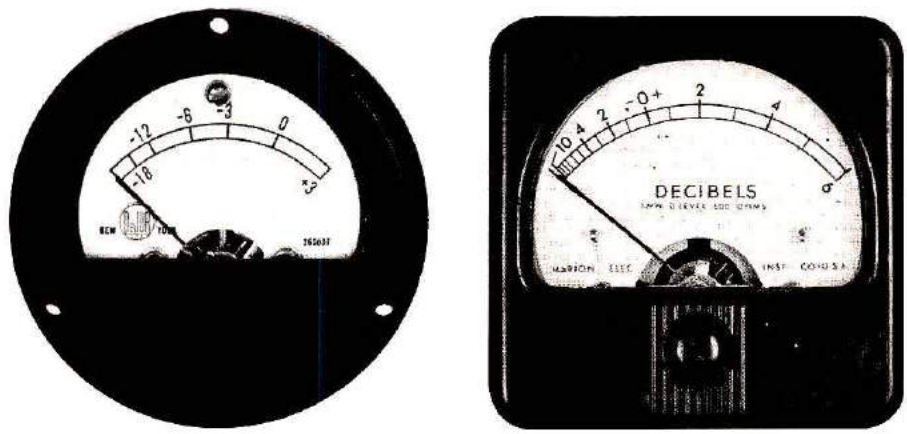
Power, rather than voltage, was selected as a basis for meter calibration to minimize the problems caused by measurements taken across lines having different impedances.

Let's pause just a moment to take a look at the term *impedance*. It comes from the word impede, meaning to hinder. Therefore, impedance is a hindrance to the flow of electrical current. Ordinarily, resistance is the word used by electronics people to describe such a hindrance, but the poor engineers had to deal with two kinds of current — direct and alternating. So, by a gentleman's agreement, it was decided long ago to use the word *impedance* to describe hindrance to the flow of *alternating* current, and *resistance* to describe hindrance to the flow of *direct* current. Thus an impedance of 600 ohms, for example, describes the hindrance a particular circuit offers to the flow of alternating current. By using Ohm's Law and substituting the value of impedance for resistance, voltage, power, and current calculations for ac circuits can be made.

So far, so good. Now let's just try to determine the voltage present at the meter terminals when the different standards are used. By a permutation of Ohm's Law, the voltage is the square root of the product of power and impedance:

$$E = \sqrt{P \times Z}$$

If we substitute the known values mentioned above for the different standards, we find that the 1-milliwatt and 600-ohm standard represents 0.7746 volt; the 6-milliwatt and 600-ohm standard represents 1.987 volts; and the 6-milliwatt and 500-ohm standard represents 1.732 volts. These were rounded off to 1.9 and 1.73 volts for meter use.[4]

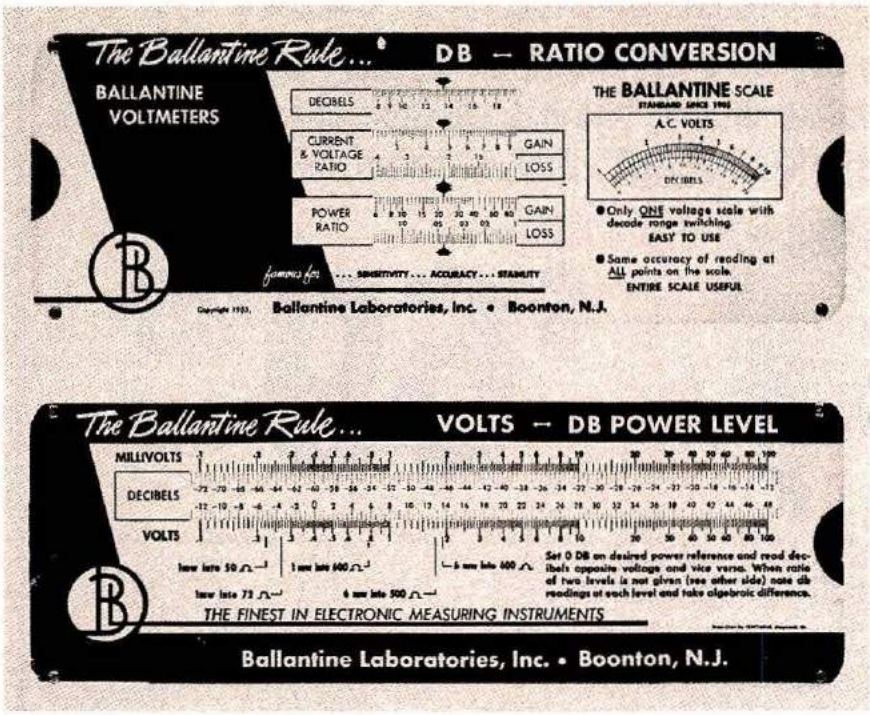



An example of the variations in scales found in dB meters is shown on these instruments. The scale on the left meter has considerable range below the 0-dB reference mark, while that on the right has more scale to the right of the reference.

### Checking dB meters

If you happen to have some dB meters lying around, and they don't have the reference voltage or standard to which they were calibrated marked on them, you can still find out, and very simply, too!

All that you need is an adjustable source of ac voltage




A Ballantine slide rule can be used for making voltage and power calculations in terms of decibels.

capable of being set to the voltage values mentioned above. Apply each of the voltages, in turn, across the meter terminals and see which one makes the meter pointer indicate the zero dB reference mark. In most cases, unless you have a very old — or perhaps foreign — meter, the zero reference will be achieved with 0.7746 volt, ac.

Of what practical value is all of this, you ask? How do you apply it to your own needs? Fair questions. Obviously, if the zero reference value is somewhere upscale on the meter and the needle indicates some other values than zero, you either have too much audio or not enough. First, notice that the values marked to the left of zero are negative values and those to the right are positive. Based upon the current standard, Ma Bell permits audio signals of +4 dB *maximum* to be applied to her telephone circuits. Inasmuch as most commercial radio stations are connected to telephone lines for transmitting program material from a remote studio to a transmitter, means for setting the audio equipment to the +4 dB level are required.[3] Such means are located at the control console of the station and are under the supervision of the engineer who "runs the board."

Sometimes it is desirable to make the setting automatic and foolproof. To do this, the engineer places a test signal of +4 dB on the circuit and mechanically adjusts the meter pointer to read zero dB reference. Now, when a program is being sent over the line and the man who handles the equipment "rides the gain" to maintain the zero reference, actually the audio level is held to −4 dB, and well within acceptable limits. This is merely a safety factor and insures that the telephone lines are not overdriven. If this amount of audio is not enough at the transmitter, it is easy for the engineer to turn up the audio gain at the transmitter to compensate, while leaving the level on the telephone lines alone.

Another way you can use the information about meter calibration is to build your own dB meter from an ac voltmeter. It is suggested that you use a meter having a full-scale deflection of about 1.5 volts. The zero-reference level would therefore be about half scale with an input of 0.7746 volt, representing 1 milliwatt across 600 ohms.

As an aid to troubleshooting or converting from one standard to another, **Tables 1** and **2** were prepared from a slide rule provided by Ballantine Laboratories. The slide rule will provide data for almost any dB calculation in

**Table 1.** Comparison of ac voltages with corresponding dB values referenced to the three commonly-used "standards" for calibrating dB meters.

| volts | 1mW/600 ohms | 6mW/600 ohms | 6mW/500 ohms |
|---|---|---|---|
| 0.1 | −17.75 | −25.5 | −24.75 |
| 0.15 | −14.25 | −22.0 | −21.25 |
| 0.2 | −11.75 | −19.5 | −18.75 |
| 0.3 | −8.25 | −16.0 | −15.25 |
| 0.4 | −5.75 | −13.5 | −12.75 |
| 0.5 | −3.75 | −11.5 | −10.75 |
| 0.6 | −2.25 | −10.0 | −9.25 |
| 0.8 | +0.25 | −7.5 | −6.75 |
| 1.0 | 2.25 | −5.5 | −4.75 |
| 1.5 | 5.75 | −2.0 | −1.25 |
| 2.0 | 8.25 | +0.5 | +1.25 |
| 3.0 | 11.75 | 4.0 | 4.75 |
| 4.0 | 14.25 | 6.5 | 7.25 |
| 5.0 | 16.25 | 8.5 | 9.25 |
| 6.0 | 17.75 | 10.0 | 10.75 |
| 8.0 | 20.25 | 12.5 | 13.25 |
| 10.0 | 22.25 | 14.5 | 15.25 |

use, but only limited information is provided by the charts.

There was a slightly different formula provided for use with the slide rule

$$V = 0.0316\sqrt{P \times R}$$

Where

$V$ = zero dB voltage
$P$ = power in milliwatts at zero dB,
$R$ = load resistance in ohms

It is unclear whether this is just for the one slide rule or provides a more accurately calculated value for other applications.

The charts are not the last word in accuracy because they have been rounded off to the nearest readable unit, but they should be accurate enough for most troubleshooting and equipment checks. If you have to set an exact standard, you'll probably want an accurately calibrated meter anyway.

**Table 2.** Decibel (dB) values with corresponding ac voltages referenced to the three commonly-used "standards" for calibrating dB meters.

| dB | 1mW/600 ohms | 6mW/600 ohms | 6mW/500 ohms |
|---|---|---|---|
| −20 | 0.078 | 0.19 | 0.172 |
| −18 | 0.098 | 0.24 | 0.218 |
| −16 | 0.123 | 0.30 | 0.275 |
| −14 | 0.155 | 0.38 | 0.342 |
| −12 | 0.19 | 0.48 | 0.438 |
| −10 | 0.245 | 0.60 | 0.55 |
| −8 | 0.31 | 0.75 | 0.69 |
| −6 | 0.39 | 0.95 | 0.86 |
| −4 | 0.49 | 1.20 | 1.10 |
| −2 | 0.62 | 1.50 | 1.38 |
| 0 | 0.78 | 1.90 | 1.72 |
| +2 | 0.98 | 2.40 | 2.18 |
| 4 | 1.23 | 3.0 | 2.75 |
| 6 | 1.55 | 3.8 | 3.42 |
| 8 | 1.90 | 4.80 | 4.38 |
| 10 | 2.45 | 6.0 | 5.50 |
| 12 | 3.10 | 7.50 | 6.90 |
| 14 | 3.90 | 9.50 | 8.60 |
| 16 | 4.90 | 12.0 | 11.0 |
| 18 | 6.20 | 15.0 | 13.80 |
| 20 | 7.80 | 19.0 | 17.20 |

### The volume unit

As mentioned before, the VU or volume unit is not an exact measurement because its value at any given moment is undergoing a change due to the presence of many different amplitudes and frequencies in the speech or music waveforms. Although there is no exact correlation between VU and dB, the two can be compared in a very practical manner with sufficient accuracy for most equipment checks and for level setting.

As we said before, dB measurements are made with a sine-wave signal (usually about 1000 Hertz, for convenience). The general rule-of-thumb is that the volume-unit indicator reaches a value of approximately 8 to 14 dB below that indicated by the dB meter under these conditions. For test purposes and to set the zero reference level, select a sine-wave voltage at least 10 dBm above the normal audio (program) level to insure that audio peaks do not exceed allowable line levels.

In a practical example, consider that you are going to set up a phone patch and want to keep the audio level in the line below the allowable limits of +4 dB.

You can beg or borrow an audio frequency generator, and may even have a dB meter. Adjust the generator output to 1000 hertz and feed it into the patch. To allow for an adequate safety margin, you might want to use 10 dB. Therefore, the maximum audio signal level should be +4 dB −10 dB, or a net −6 dB. You can now manually adjust the meter to read 0 dB at that level, or you can install a 6-dB attenuator pad in the line and feed the true 0-dB signal to the attenuator pad and then to the telephone lines.

Once the meter is set up with a suitable reference zero level for safe use, the signal generator can be disconnected and the circuit attached directly to the audio source you intend to use, whether it be output from your speaker terminals, a tape recorder, or some other device. By watching the signal level on your now-calibrated meter, you can adjust the audio gain controls on the equipment to keep the signal level hovering around zero — the preset, "safe" level. For most purposes, a good vacuum-tube voltmeter or a vom (volt-ohm-milliammeter) may be used in the low-voltage ac scale position as a satisfactory dB meter.

Modest equipment backed up with the knowledge of how to use it will produce professional results. Good luck and happy VUing.

### References


1. H.A. Chinn, "The Measurement of Audio Volume," part I, *Audio Engineering*, September, 1951, page 26.
2. H.A. Chinn, "The Measurement of Audio Volume," part II, *Audio Engineering*, October, 1951, page 24.
3. Edward M. Noll, *First-Class Radio Telephone License Manual*, 2nd edition, page 72.
4. *Latest Instruments For Servicing Radio-Television*, Coyne Electrical School, Inc., 1960, page 148.
5. *Ballantine Slide Rule*, Ballantine Laboratories, Inc., Boonton, New Jersey 07005. **HRH**